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ASSESSING INTER-LIMB ASYMMETRIES: ARE WE HEADING IN THE RIGHT DIRECTION?

ABSTRACT

The investigation of inter-limb asymmetries has increased in recent years, with practitioners and researchers typically exploring the impact of inter-limb asymmetry on athletic performance, screening inter-limb asymmetry in relation to injury risk, and monitoring of inter-limb asymmetry during injury rehabilitation. A contentious issue regarding the profiling of inter-limb asymmetry is the use of thresholds to determine whether an athlete displays a ‘meaningful’ or potentially ‘problematic’ asymmetry and how to interpret such data. This article aims to outline the potential options available for practitioners and researchers regarding the quantification, monitoring, and interpretation of inter-limb asymmetries.

Keywords: between-limb difference; side-to-side difference; imbalance; symmetry; muscle strength asymmetry

INTRODUCTION

An inter-limb asymmetry is a difference in performance or function of one limb with respect to the other (17), and can be generally, but not exclusively, categorised into the following: anatomical or morphological asymmetries (e.g., lean mass difference between left and right limbs) (38, 39); flexibility asymmetries (e.g., ankle dorsi-flexion range of motion difference between left and right limbs) (40, 62); strength asymmetries (force asymmetries – e.g., isokinetic peak torque or countermovement jump [CMJ] propulsive force difference between left and right limbs); strategy asymmetries, (e.g., CMJ negative displacement or propulsion duration difference between left and right limbs); and skill or outcome asymmetries (e.g., difference in change of direction time or CMJ height between left and right limbs) (40, 55). Due to laterality, humans will preferentially use one side of the body when performing a motor

task; typically resulting in more skilful and therefore dominant side (26, 38, 55), thus it is unsurprising that athletes tend to display inter-limb asymmetries. In specific sporting contexts, inter-limb asymmetries arguably are a functional adaptation (55, 60), potentially due to the chronic exposure to repeated asymmetrical sport-specific actions, such as fencing (43) or badminton lunge and striking actions (1, 55), kicking actions in soccer (4, 5, 25, 58) and Australian rules football (38, 39), and asymmetrical throwing, bowling, and batting actions performed in cricket (14, 48).

Investigations into inter-limb asymmetry have increased in popularity over recent years, with research in this area typically focusing on the following: 1) impact of inter-limb asymmetry on athletic performance (20, 55); 2) the screening and profiling of inter-limb asymmetry in relation to injury risk (23, 40, 41, 47, 49); and 3) monitoring of limb function and inter-limb asymmetry during the injury rehabilitation process (40, 46, 49, 64, 65); particularly rehabilitating from anterior cruciate ligament (ACL) injury (40, 46, 49, 65). Whether inter-limb asymmetries manifest into performance decrements and increases injury risk is a contentious issue, with mixed findings observed (8, 20, 23, 33, 40, 47, 55), but nevertheless an asymmetry and imbalance can be viewed as a ‘window for development’ to improve the performance and function of the non-dominant limb (55). A plethora of work from researchers have outlined recommendations as to how to calculate, assess, and monitor inter-limb asymmetries which has contributed to our insight and knowledge in this area (6, 8, 11, 16-22, 55). However, we feel that there are gaps in the literature pertaining to the methods of quantifying, interpreting, and monitoring inter-limb asymmetry, and some of the associated issues when collecting and interpreting inter-limb asymmetry data need to be further highlighted. Additionally, and importantly, to the best of our knowledge, a framework for practitioners to help inform and assist in the preparation, assessment, analysis, and interpretation of inter-limb asymmetry data does not exist.

The purpose of this article is to outline the potential options available for practitioners and researchers regarding the quantification, monitoring and interpretation of inter-limb asymmetries. Additionally, a further purpose is to outline a framework for practitioners to help inform and assist in the preparation, assessment, analysis, and interpretation of inter-limb asymmetry. Strength (30, 31, 67), strategy (16, 56, 65), and skill (32, 34, 56, 68) inter-limb asymmetries have been commonly investigated over recent years in the area of strength and conditioning and thus, will be the primary focus for this article.

Is my athlete asymmetrical? Using asymmetry thresholds and asymmetry considerations

A plethora of assessments are available to practitioners to evaluate strength and skill asymmetries in athletes (19, 40, 44, 67), and a range of equations are available for practitioners to evaluate inter-limb asymmetry which can result in different percentage magnitudes (6, 17, 18, 40). As such, practitioners are encouraged to follow the recommendations of previous work for calculating inter-limb asymmetries during unilateral and bilateral assessments (18, 40). When calculating an inter-limb asymmetry, a percentage figure is created, but a problematic issue for the practitioners is how to interpret this value (8). Traditionally, a 10-15% imbalance has been viewed as a potentially problematic asymmetry (7, 8, 40, 45, 47, 61), and this arbitrary threshold has been typically used to classify asymmetry over the last 20 years (8, 40). Recent work (8) has excellently highlighted the problems associated with using an arbitrary inter-limb threshold (i.e., 10-15% threshold) which cannot be applied across all assessments and metrics, due to the problems of the task- and metric-dependent nature of inter-limb asymmetries (2, 16, 30, 31, 35, 37, 40, 67). As such, recent work regarding asymmetry thresholds has (8) advocated the approach recommended by Exell et al. (36) that an 'asymmetry might only be meaningful if the percentage value is greater than the test variability score' (i.e., coefficient of variation [CV%]), and recommends that an individual approach should be adopted when monitoring inter-limb asymmetries.

Indeed, it is not disputed that that an arbitrary threshold cannot be universally applied across all assessments and metrics due to the task- and metric-dependent nature of inter-limb asymmetry (16, 40, 67), and we agree that the inter-limb asymmetry percentage value should exceed the variability for the specific metric of a task. However, if an individual displays variability of 2% for a specific metric, with an inter-limb percentage difference of 3%, although ‘real’, it in all probability does not represent a problematic asymmetry in terms of athletic performance and injury risk. In this example, an asymmetry value so low and close to zero would be questionable to suggest using solely such an approach when interpreting an individual’s inter-limb asymmetry. This is pertinent when research examining whether asymmetry is a problem does not reveal a clear relationship, particularly because typical asymmetries for certain metrics and tasks are relatively low (20, 31, 35, 40, 55, 67). Alternative methods we feel are applicable, or methods that have been used previously, will be discussed in the following sections to assist in the interpretation of inter-limb asymmetry.

While we agree that an individual approach is needed regarding the monitoring of inter-limb asymmetries (8, 11), and monitoring of variables in general in strength and conditioning (i.e., training load, fatigue, interventions etc.) (57), it is difficult to adopt such an approach and interpret data without benchmark, criteria, or normative data related to the metric, task, and population in question. Unfortunately, recent work which has discussed the concept of inter-limb asymmetry thresholds (8) fails to discuss some asymmetry thresholds that have been utilised in the literature, including thresholds for metrics based on the population mean + smallest worthwhile change (SWC) ($0.2 \times$ between-subject standard deviation [SD]) (31, 35, 40, 51, 52), mean + ($0.5 \times$ between-subject SD) (40), or population mean + ($1.0 \times$ between-subject SD) (2, 37, 40, 67, 68). Assuming the associated asymmetry of the metric is normally distributed, the proportion of athletes deemed ‘asymmetrical’ based on the abovementioned thresholds would be ~42%, ~31%, and ~16%, respectively, and may provide practitioners with

the option to classify individuals in their population with ‘small to moderate’ or ‘high or extreme’ asymmetries. The aforementioned thresholds have been used to establish benchmarks in athletic populations, and have been used to assess the agreement in the direction of asymmetry between tasks and metrics (2, 31, 35, 37, 67); highlighting the task- and metric-dependent nature of inter-limb asymmetry.

It is important to note that inter-limb asymmetry may not always be parametric because of the range of asymmetry values observed for particular metrics and athletic populations and the small sample sizes often used by researchers and practitioners. Thus, practitioners should ensure that they inspect the normality of their inter-limb asymmetry data when adopting and aiming to use the aforementioned thresholds. Practitioners with non-parametric data may consider looking at the median and interquartile range of their data to assist in the interpretation of inter-limb asymmetries for a specific metric within their population. In this scenario, the upper quartile could be used to represent athletes with potentially ‘high or extreme’ asymmetries.

We are not, by any means, suggesting that this a perfect solution, but the approach of using the mean + SWC and mean + SD for asymmetry thresholds allows practitioners to create benchmarks, criteria, and normative data that are specific to their athlete population for a range of metrics and tests. Specially, the aforementioned thresholds allow practitioners a method of classifying athletes with ‘small to moderate’ and ‘extreme or high’ asymmetries, respectively. The mean + SWC threshold is a more sensitive approach which will classify a greater proportion of athletes (~42%) with ‘small to moderate’ inter-limb asymmetries. Conversely, the mean + $(1.0 \times \text{between-subject SD})$ threshold is a more conservative approach which will classify a smaller proportion (~16%) of athletes with ‘high or extreme’ inter-limb asymmetries. It should be noted that neither threshold is superior, but both should be used in combination to provides descriptors to the magnitude of the asymmetry (for example, similar to the thresholds

and descriptors used for an effect size scale) to assist in the interpretation and classification of inter-limb asymmetry. The concept of interpreting data relative to the population mean and using the SWC for monitoring changes in fitness and training load data is common practice in Sports Science and Strength and Conditioning (57). Consequently, athletes that display inter-limb asymmetries greater than the population mean + SWC, and their individual variability (CV%), can therefore be potentially interpreted as displaying ‘meaningful’ or ‘greater’ asymmetry in context of the population and metric for a specific test.

While investigating inter-limb asymmetry is indeed insightful into athletes’ physical profiling and has been advocated in sporting and clinical setting (19, 22, 40), it is important that practitioners should be aware of some key considerations that may influence the evaluation of inter-limb asymmetry profiles (Figure 1). For example, previous work has highlighted that the magnitudes and directions of inter-limb asymmetry are not necessarily consistent between-sessions (16), and are also sensitive to acute (12) and post-match fatigue (immediate, 24, and 48 hours post fixture) (24). As such, practitioners are encouraged to establish the between-session reliability for inter-limb asymmetries to ensure that the magnitude (i.e., % imbalance) and direction (limb displaying greater function or performance) is consistent between sessions before classifying athletes as asymmetrical. It is recommended that a combination of statistical tests are used to assess for systematic bias (e.g., paired sample t-test or non-parametric equivalent), within-subject variation (e.g., CV%, typical error, or standard error of measurement), and retest correlation (e.g., intraclass correlation coefficient) for a more holistic overview of reliability (3, 42, 53). Additionally, practitioners should ensure that they evaluate their athletes’ inter-limb asymmetries in a non-fatigued state (12, 24); ensuring that their athletes are sufficiently recovered from competitive matches so that any large imbalances observed are not attributed to fatigue. Finally, practitioners should acknowledge that asymmetries may fluctuate throughout a competitive season or macrocycle

(15), though further research is necessary to better understand how asymmetry changes throughout the season and macrocycle.

Insert Figure 1 here

Inter-limb asymmetry: data visualisation and interpretation

Recent work (8) has presented illustrative methods for interpreting individuals' asymmetry values relative to their variability. We agree that this is a useful method for illustrating and monitoring inter-limb asymmetries; however, we feel that the addition of asymmetry threshold lines (mean + SWC) and 'high' asymmetry threshold lines (mean + SD) are useful additions to assist in the interpretation of asymmetries for athletes in a specific population (40). For example, Figure 2 illustrates hypothetical individual unilateral isometric mid-thigh pull (IMTP) peak force (PF) inter-limb asymmetry values, individual CV% values, and the asymmetry thresholds calculated on the population mean + SWC and mean + SD. The mean asymmetry IMTP PF value was $6.5 \pm 3.9\%$, resulting in asymmetry thresholds of 7.3% (small to moderate) and 10.4% (high / extreme) which is specific to this population and metric during this test. In this example, 11 athletes displayed asymmetries greater than their individual CV%, but only 6 athletes displayed asymmetries which exceeded the asymmetry threshold (Figure 2). However, it is worth noting that, despite displaying an asymmetry greater than the asymmetry threshold, the asymmetry for Athlete 6 was not greater than the CV%, and therefore cannot be interpreted as 'real'. As such, 2 athletes (Athlete 8 and 11) displayed asymmetries greater than their individual CV% and 'small to moderate' asymmetry threshold, while 3 athletes (Athlete 1, 7, 12) displayed 'high' asymmetries which were also greater than their individual CV% (Figure 2). However, practitioners should be mindful that if the CV% is $>10\%$, therefore considered unacceptable absolute reliability (29, 59), interpreting asymmetry for that metric and / or athlete is likely sub-optimal. Therefore, it is advised that practitioners investigate metrics during tasks

that display low variability, and ensure that athletes are adequately familiarized with the task and assessment procedures to improve data collection and subsequent analysis and interpretation.

Insert Figure 2 here

Alternatively, practitioners may also consider calculating Z-scores of their inter-limb asymmetries for their population, to identify which athletes display asymmetries greater than average (Figure 3), and may consider using Z-score benchmarks of 0.20-0.99, and ≥ 1.00 to classify athletes with ‘small to moderate’ and ‘extreme or high’ asymmetries (40), respectively. The procedure of using Z-scores is commonly advocated and used in practice when interpreting strength, power, and fitness data (57, 69).

Insert Figure 3 here

Inter-limb asymmetry is a percentage / ratio: do not forget the absolute components when interpreting and profiling

While the inter-limb percentage figure is indeed a simple method for indicating deficiencies in performance between the dominant and the non-dominant limb, and a useful communication approach, the above-mentioned proposed asymmetry thresholds calculations can also be applied to raw scores. Statistically, a raw score may be more accurate to consider as this will not be dependent on changes to the denominator; therefore, arguably, a percentage index may only be appropriate for monitoring changes in inter-limb asymmetry if the dominant limb increases or decreases (either between or within subjects) in direct proportion to the non-dominant limb for a metric of interest. Practitioners are encouraged to refer to previous work which acknowledges some of the issues of calculating percentage differences and percentage changes (27, 28). As such, it is recommended that the absolute components (i.e., numerator

and denominator) must also be acknowledged and considered when interpreting and making decisions regarding an athlete's physical profile (Figure 1).

As previously stated, when interpreting an athlete's physical profile, it is critical that coaches interpret the absolute components (i.e., numerator and denominator). For example, an athlete may be strong or display high function or performance and asymmetrical, but their weaker or lower functioning limb may still outperform the rest of the squad or exceeds normative data or benchmark criteria. Nevertheless, the non-dominant limb can still be viewed as a 'window for development' (55). Conversely, an athlete may display similar strength and function or performance between limbs and would therefore be classed symmetrical, but inspection of the absolute measures may indicate that the athlete is weak or has poor function and the worst performer for that metric in the squad or when compared to normative data. Arguably, the symmetrical but weak or poor function athlete arguably warrants greater attention and strength and conditioning support. Figure 4 illustrates four quadrants to assist in the physical profiling of athletes. The optimal scenario for practitioners is athletes who are equally strong and displaying high function and performance from both limbs, which should be viewed as the ultimate aim for strength and conditioning practitioners (Figure 4 – green). Conversely, the worst case and 'red flag' scenario for practitioners is identifying a weak or low function and asymmetrical athlete (Figure 4 - red).

Insert Figure 4 here

It should be noted that although an athlete's magnitude of asymmetry may not change longitudinally, the absolute components may increase which can still be viewed as positive adaptation because the athlete has improved their strength, function, or performance in both limbs proportionately. Equally, however, athletes may maintain similar asymmetry values longitudinally, but the absolute components have reduced proportionately (i.e., weaker,

reduced function, or performance in both limbs) which is problematic with respect to athletic performance and potential injury risk (54, 66) (Figure 5a). Additionally, from an injury rehabilitation monitoring perspective, athletes have been reported to display reductions in inter-limb asymmetries (limb-symmetry index) during rehabilitation where this was attributed to reductions (detraining) in strength and performance of the contralateral (i.e., dominant limb) limb (64). This is therefore problematic, particularly in the context of ACL injury, as the contralateral limb is typically at greater risk of injury following an ACL injury (63). Thus, practitioners should ensure that when monitoring inter-limb asymmetries, they inspect the absolute (raw) values because an athlete can reduce their % imbalance via reductions in dominant limb strength, performance, or function, while maintaining strength, performance, or function in the non-dominant limb (64) (Figure 5b).

Insert Figure 5 here

Direction of asymmetry: future directions for research

Finally, we agree that the direction of asymmetry is a key factor to acknowledge when monitoring inter-limb asymmetries (i.e., asymmetry favouring the same limb between metrics and / or tasks) (8, 22) and recent work (8) advocates the use of Kappa coefficients to assess the agreements in limb dominance (i.e., limb producing greatest value or best performance) between metrics, tasks, and sessions to assist in inter-limb asymmetry profiling. However, previous research which has utilised this approach have only determined if the direction of asymmetry favours the left or right limb between tasks, metrics, trials, or sessions, but not quantified the agreements in 'real' asymmetries (i.e., did the same limb exceed the CV% for both metrics / task / sessions) (9-11, 13, 16, 50). Thus, it appears that agreements in limb dominance performed by previous studies have classified limbs as left or right dominant without accounting for individual variability (9-11, 13, 16). Consequently, as emphasis has

been placed on ensuring the inter-limb asymmetry exceeds the variability (8, 22, 36), it would be more suitable to assess agreements in ‘real’ asymmetries for left and right limbs between metrics, tasks, or sessions, with inter-limb asymmetries \leq CV% considered ‘trivial’, ‘unclear’, or ‘balanced’. Additionally, it may also be worthwhile to assess the agreements in asymmetries greater than the asymmetry thresholds (i.e., mean + SWC and / or mean + SD) to improve our understanding regarding the direction of inter-limb asymmetries.

PRACTICAL APPLICATIONS

Whether inter-limb asymmetries manifest into performance decrements and increases injury risk is a contentious issue (8, 20, 23, 33, 40, 47, 55), but for most athletes it would advantageous to be equally strong and possess high function and performance for both left and right limbs. As such, an asymmetry can be viewed as a ‘window for development’ and may warrant greater training focus to improve the performance and function of the non-dominant limb (Figure 4) (55). However, it should be noted that the dominant limb should not be neglected, and practitioners should still seek to improve performance and function in the dominant limb.

The investigation of inter-limb asymmetry has increased in popularity over recent years, with a plethora of articles outlining practical recommendations for the assessment, calculation, and interpretation of inter-limb asymmetries (6, 8, 11, 16-22, 55). The primary purpose of this article was to outline the potential options available for practitioners and researchers regarding the quantification, monitoring and interpretation of inter-limb asymmetries. In summary, Figure 1 presents key considerations related to the task, athlete, and interpretation which should be acknowledged by practitioners when monitoring inter-limb asymmetries. Figure 6 presents a framework for practitioners to help inform and assist in the preparation, assessment, analysis, and interpretation of inter-limb asymmetry data.

Insert Figure 6 here

Consequently, to improve inter-limb asymmetry profiling and research, we suggest that practitioners and researchers should consider the following recommendations:

1. Create asymmetry thresholds based on population mean + SWC ($0.2 \times$ between-subject SD) and population mean + ($1.0 \times$ between-subject SD) to allow practitioners a method of classifying athletes with 'small to moderate' and 'extreme or high' asymmetries. This enables practitioners to create benchmarks, criteria, and normative data that are specific to their athlete population for a range of metrics and tests. The mean + SWC threshold is a more sensitive approach which will classify a greater proportion ($\sim 42\%$) of athletes with 'small to moderate' inter-limb asymmetries. Conversely, the mean + ($1.0 \times$ between-subject SD) threshold is a more conservative approach which will classify a smaller proportion ($\sim 16\%$) of athletes with 'high or extreme' inter-limb asymmetries. It should be noted that neither threshold is superior, but both should be used in combination to provide descriptors to the magnitude of the asymmetry (similar to the thresholds and descriptors used for an effect size scale) to assist in the interpretation and classification of inter-limb asymmetry.
2. Athletes which display asymmetries which exceed their individual CV% and population asymmetry (mean + SWC / mean + SD) can be interpreted as displaying 'small to moderate' or 'high or extreme' asymmetries.
3. Practitioners may consider creating combined column and line charts (Figure 2) as a data-visualisation method for interpreting inter-limb asymmetry. Additionally, practitioners should also consider using Z-scores when interpreting inter-limb asymmetry (Figure 3).
4. Practitioners should consider establishing the between-session reliability for inter-limb asymmetry metrics to ensure that the magnitude and direction of asymmetry is consistent between sessions. Consequently, it is recommended that a combination of statistical tests (e.g. statistical tests for systematic bias, within-subject variation, and retest correlation) are used for a more holistic overview of reliability (3, 42, 53). Additionally, when collecting

inter-limb asymmetry data, practitioners should ensure that data is collected in a non-fatigued state, with data collected with sufficient recovery from previous matches (i.e., >96 hours).

5. Practitioners are advised to evaluate the absolute components (raw values) of the inter-limb asymmetry metric, in addition to the percentage value, to assist in physical profiling and training prescription (Figures 4 & 5).
6. Acknowledge the key factors which can impact the collection and interpretation of inter-limb asymmetry data (Figure 1), and use the framework (Figure 6) to help inform and assist in the preparation, assessment, analysis, and interpretation of inter-limb asymmetry data.

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